MCP-Optics for X-ray Timing

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Abstract.

Very lightweight X-ray optics are being developed by ESA and its industrial partners, for a number of X-ray astronomy and planetary missions. These developments could significantly improve the performance of future X-ray timing instrumentation. Based on Micro-Channel Plates (MCPs), the novel optics effectively reduce the mirror thickness by almost two orders of magnitude, and therefore also the mass of the telescope optics. Very large collecting areas become feasible for space implementation, especially as required for X-ray timing observations. Furthermore this technology leads to much reduced detector sizes due to the use of imaging X-ray optics. This dramatically improves the detected signal-to-noise ratios, as well as introducing photon collection areas sufficiently large as to study temporal phenomona on the millisecond time scale. This is particularly important to improve the studies of compact X-ray sources, both for improving the signal:noise ratios in temporal bins so that spectral or fluctuation analyses are improved, and for extending the range of measurements to fainter classes of objects.

We present a brief overview of the MCP optics technology, and some basic design rules relevant to such systems. The performance of such optics and some possible mission implementations will be discussed.

INTRODUCTION

Micropore optics [1, 2, 3, 4], being very light weight (a few kilograms per square meter) and of intermediate imaging quality (0.5 arcmin anticipated) are good candidates for a large area optic for X-ray timing experiments. In this paper we propose and analyse the use of such optics for X-ray timing applications.

Microchannel plates have been developed and reached high levels of optimisation for applications in image intensifiers and photo-counting detectors. However for applications in optics, the basic pore geometry has had to be changed from round to square, in order to provide the true orthogonal focussing capability. The production process is schematically described in Figure 2.

The resulting MCP optics is very rigid and extremely light. In fact the optics structure is also very robust. The specific mass is low, and it can be anticipated that during launch of a payload the corresponding forces resulting from vibration are also low.

The imaging performance measured with one of the first prototypes is shown in Figure 1. Two MCPs are required to produce a real image of the sky onto the detector. By appropriately bending the MCPs a conical approximation to the Wolter-I design is achieved, see Figure 3.

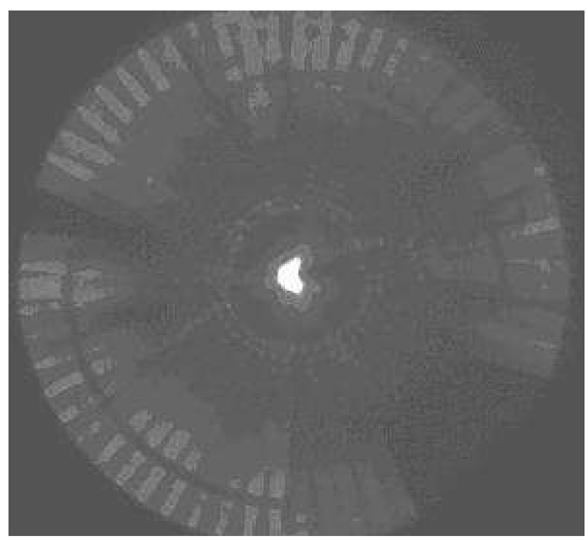

FIGURE 1. X-ray optical performance of a single radially packed MCP, measured at the European Synchrotron Radiation Facility. The X-ray energy was 10 keV, the diameter of the illuminated optics was 40 mm, with sequential exposure. The HEW was measured as 33", and the FWHM as 20"

FIGURE 2. Production of glass based MCPs with radial geometry. The core glass has a higher melting point than the cladding glass, and therefore remains stiffer and defines the shape of the interface between core and cladding during the drawing process forming the primary fibers. The starting glass slab is stretched by a factor of 20 to 100, thereby improving the surface roughness by stretching any surface structures. The primary fibers are assembled into multifibre bundles, which are fused and drawn again. These secondary multifibers are assembled into the required radial geometry and fused. Finally the block is cut into slices, slumped to the required shape and etched

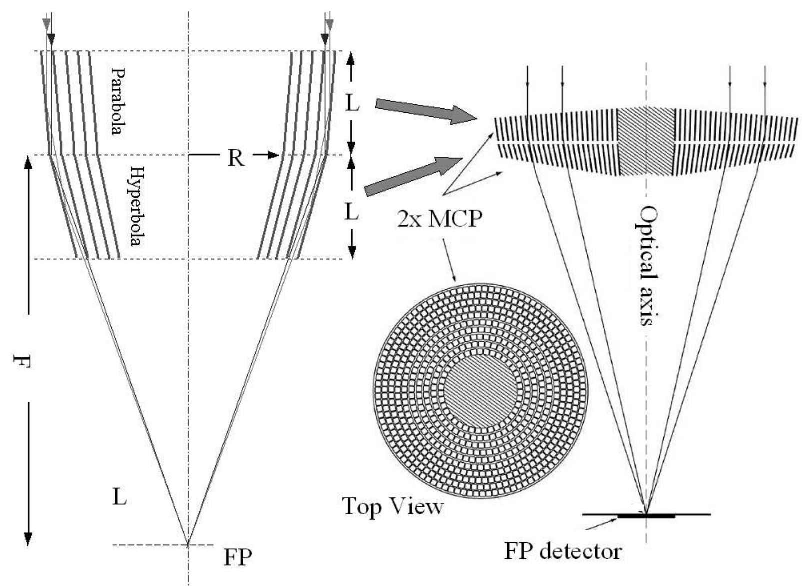

FIGURE 3. The MCP optics represents a conical approximation to the Wolter-I design. The key parameters of such systems are the focal length F, the length of the optics L, and theradius R (left). To increase the effective area under the grazing incidence, a large number of concentric reflectors is used. By implementing the concentric mirrors in two MCPs (right), the packing density increases and the mirror thickness can be substantially reduced due to the radial walls stabilizing the optics.

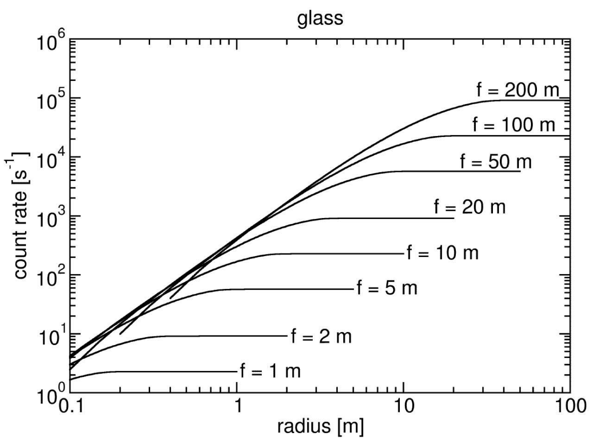

FIGURE 4. The expected count rate for a 1 mCrab source using a micropore optics made from 297 glass. Different configurations of diameter and focal length have been assessed.

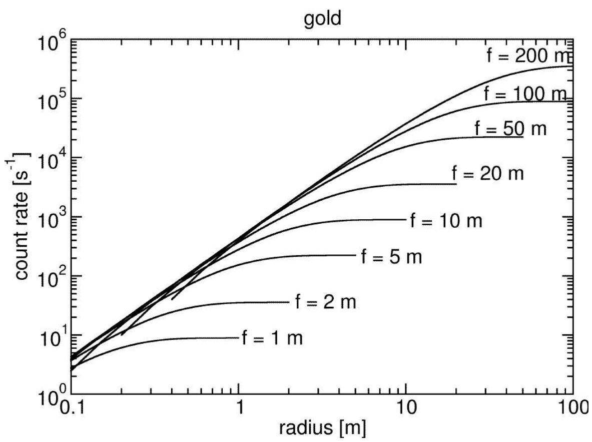

FIGURE 5. The expected count rate for a 1 mCrab source using a micropore optics assembly with a gold coating inside the pores.

SIMULATIONS

Simulation implementation

A generalised ray-trace code for X-ray telescope systems has been developed from the XMM-Newton Science Simulator package [5], and applied to the MCP optics configuration. We calculated the count rates that could be observed from a typical source as a function of the radius and focal length of the micropore optic assembly.

We assume for a typical source that it has a powerlaw spectrum (E^{-2}), a column density of $N_H = 3\times10^{21}$ and a brightness of 1 mCrab. At this flux level a considerable number of interesting sources are expected [6, 7, 8]. In order to observe millisecond variations of a periodic nature, of the order of 10^3 counts per second would be required, while to observe transient events at millisecond scale more counts are naturally required. For example, an X-ray burst which lasts for 30 s and has 10% variations at millisecond time scale must be detected at a count rate of $\sim 10^5$ per second. The results of the simulations displayed can therefore be used to determine minimum dimensions of a scientifically credible optics design in this MCP technology.

We assume a detector with 100% QE over the energy band 0.5 to 5 keV and an open area ratio of 70% for the micropore optics. Following a Monte Carlo ray-trace of photons through the system, we summed all simulated events in this energy band.

Results

Figure 4 shows the expected count rates for a micropore optic made from glass without coating (297 type) as a function of radius of the optical assembly, for a set of different focal lengths. Figure 5 shows the equivalent results for a micropore optic that is coated internally with gold. A glass optic with 50 m focal length and 2 m radius would provide of the order of 1000 cts/s for a 1 mCrab source. For a gold optic a focal length of 20 m would be sufficient for the same count rate. A rate of 10^5 cts/s could be obtained with a gold-coated optic of radius 20 m and a focal length of 200 m.

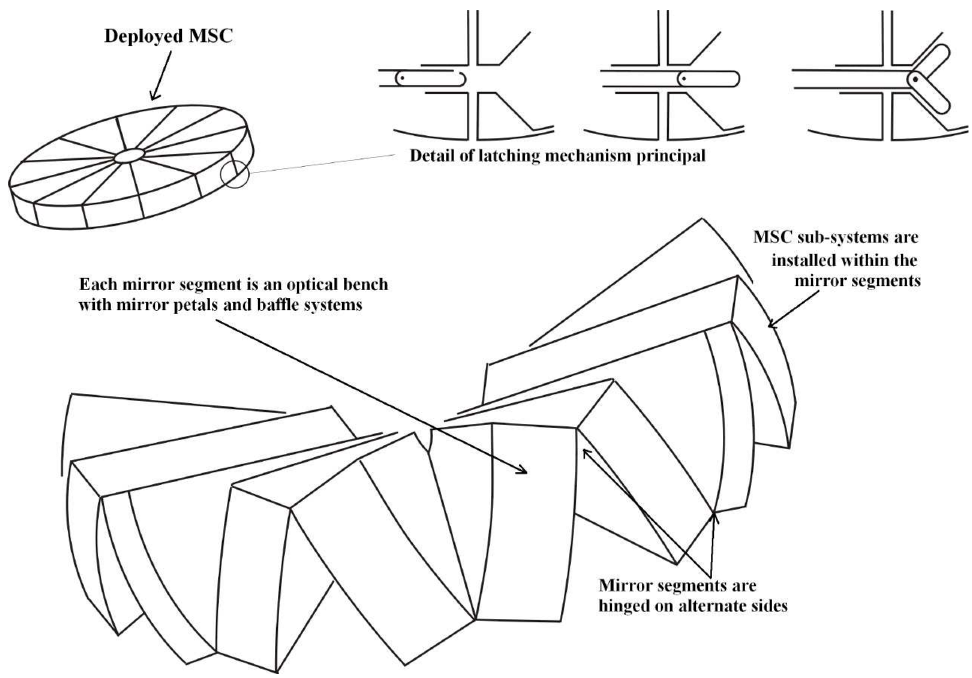

FIGURE 6. Deployment scheme for the optics elements. The deployment occurs automatically and the elements are finally interlocked using a split-pin mechanism as the baseline design. A rigid optical bench is produced, and the optics as well as the straylight and thermal baffles are deployed in the required geometry, starting from a very compact launch package

DISCUSSION AND CONCLUSIONS

Even though the optics diameter and focal length that is required for 10^3 to 10^5 cts/s from a 1 mCrab source seems to be very large, the weight of such an optic would not be prohibitive. Given the moderate imaging quality requirements ($\sim$1 arcmin) it should be possible to build such an optic with a minimum amount of structure.

Note that also higher energies can be efficiently imaged by MCP-based optics, by using smaller incidence angles. The efficiency of the system for lower energies would however be somewhat reduced.

The required large effective area of the optics would require an appropriate stowage for launch and a deployment in space. Figure 6 shows one possible stowage and deployment scheme, which would permit the use of a rather small launcher to deploy the very large optics (6 to 10 m diameter).

For some long focal lengths we assume that a separate focal plane detector spacecraft DSC is required to fly in formation with the spacecraft (MSC) carrying the mirrors. This formation flying approach is not seen as a special challenge, because many such schemes are being developed, and the modest imaging response of this timing mission poses relaxed relative pointing requirements for the spacecraft pair.

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